The individual as the key-stakeholder of Next Generation Infrastructure

Kalyviotis, Nikolaos; Rogers, Christopher; Tight, Miles; Hewings, Geoffrey J. D.; Doloi, Hemanta

INTERNATIONAL SYMPOSIA FOR
NEXT GENERATION
INFRASTRUCTURE

The individual as the key-stakeholder of Next Generation Infrastructure: Defining the social value of transport infrastructure in the United Kingdom

Nikolaos Kalyviotis
University of Birmingham & University of Illinois Urbana-Champaign

Chris D.F. Rogers
University of Birmingham

Miles R. Tight
University of Birmingham

Geoffrey J.D. Hewings
University of Illinois Urbana-Champaign

Hemanta Doloi
University of Melbourne

Abstract

The idea of social value has arisen from the psychological approach, and more specifically it is based on the principle of "independence of irrelevant alternatives" from the game theory introduced by Luce and Raiffa[1]. According to this, each alternative situation (j) has an utility/value (V_{ij}) for the individual, which is a function of the features of the alternative situation (X_j) and of the features of the individual who makes the choice (S_i): $V_{ij} = V(X_j, S_i)$. Beyond that, it assumed that the individual, who makes the choice, has a clear and measurable knowledge of the value, which each choice provides. Although even after the evaluation of each choice, it is a tentative situation regarding the choice of the individual. In other words, there is an element of possibility. Under the same principle of Luce and Raiffa, the possibility of a choice is in direct ratio to its value. The above mentioned assumptions constitute the "strict utility choice mode". The exponential form of the value function: $V_{ij} = \exp[V(X_j, S_i)]$ is achieved by simple transformations of the "strict utility choice mode", where X and S have a linear correlation. The exponential functions of the total value have a sigmoid form relative to the linear function of the value of the possible choice. This means that the exponential function may have a sigmoid form relative to the X-axis or Y-axis, based on the defined axes and values. The key challenge addressed is a quantitative sense of value, when the perceptions of value are qualitative. To measure social value quantitatively is challenging, since it is observed that pricing systems are "not based primarily on the

[1] Luce, R.D. & Raiffa, H. Games and Decisions. (New York: John Wiley and Sons, 1957).

users' identity or activity", but on the ability and willingness of the final user to pay[2]. The social value gained by the individual is difficult to calculate, since it is defined by human behaviour and human needs. According to Maslow's Hierarchy of Needs[3], these needs belong to specific groups with specific hierarchy. Maslow developed value (utility) curves of each category of need relative to the age of the individual. The sum of the curves gives an almost sigmoid curve. Winters et al.[4] created a Transportation Hierarchy of Needs and they found the following transport hierarchy of needs: [1] safety and security, [2] time, [3] societal acceptance, [4] cost and [5] comfort and convenience. This research studied value as something holistically affected by all the above factors (time, cost, comfort and convenience, safety and security), without considering their ranking, by asking individuals representative of the UK's demography to evaluate the social value of eight transport modes (walking, cycling, rail, bus, car, taxi, water and air) and each factor for each mode with a questionnaire survey. The hypothesis tested is that the value to the individual, collectively, from the aforementioned factors should have an almost sigmoid curve, which was verified. After analysing and comparing some sigmoid functions, the two which mostly align with the curve are: $f(x) = \tanh(x)$ and $f(x) = \mathrm{erf}(\frac{\sqrt{\pi}}{2}x)$ [where $f(x)$: the social value of each transport mode to the individual, x: the sum of the values of the factors defining the social value to the individual; when $x \in [-2.5,\ \ 2.5]$]. The social value function fits with the hyperbolic tangent function, which is defined for all real numbers and is a strictly monotonically increasing function. It is obvious that its maxima ($\nabla f = gradf = 0$) will be achieved at the infinity, but of interest to this study is where the rate of change achieves the maxima ($f'' = 0$), as after that point the rate of the return of the value to the individual starts to reduce. This way it will be possible to evaluate each transport infrastructure investment by defining its aforementioned factors aligned with the political decisions and assumptions made by the investor.

Key Words

Infrastructure; Social Value; Business Model

Introduction

The infrastructure systems that operate in countries and cities are interrelated in different ways, but all have a strong relationship to 'transport' – there is a cost and a utility associated with movement. Infrastructure systems are ultimately created to serve individuals, who place a value on them. In order to explore all forms of investment and value realisation – what is commonly termed a business model – the relationship between an individual and the transport systems needs to be established. The hypothesis being tested in this research is that it is possible to identify both the full range of value created and investments required, and hence to establish a robust business model for transport systems.

[2] Frischmann, B.M. Infrastructure: The Social Value of Shared Resources. (New York: Oxford University Press, 2012).

[3] Maslow, A. Motivation and personality. (New York, NY: Harper, 1954).

[4] Winters, P.L., Cleland, F., Mierzejewski, E. & Tucker, L. Assessing Level of Service Equally Across Modes. A report for the Florida Department of Transportation and NCTR: 1-53 (2001).

This research will focus on the social value in transport infrastructure investments. The economic value invested by the government on behalf of the individuals can be easily calculated based on data by the Office for National Statistics. The social value gained from (i.e. invested by) the individual are difficult to calculate due to the different behaviour of each individual.

Theoretical Frame of Reference

The challenge of the collective behaviour can be sorted out by considering the individual user as a rational key-stakeholder and not as the final user. The individuals living in the specific urban area may be considered as a "key stakeholder", since they set out the government and previous studies have shown that transport infrastructure investment alone is not significantly linked with regional growth, but its success is more strongly linked to growth in regions with better government quality [5].For the above reasons this study will focus on the social value, which effects and get affected from the citizens, who are the key-stakeholders. The idea of social value arose from the psychological approach, and more specifically it is based on the principle of "independence of irrelevant alternatives" from the game theory introduced by Luce and Raiffa[6]. According to the principle of "independence of irrelevant alternatives", each alternative situation (j) has an utility/value (V_{ij}) for the individual, which is a function of the features of the alternative situation (X_j) and of the features of the individual who makes the choice (S_i): $V_{ij} = V(X_j, S_i)$. Beyond that, it assumed that the individual, who makes the choice, has a clear and measurable knowledge of the value, which each choice provides. Although even after the evaluation of each choice, it is a tentative situation regarding the choice of the individual. In other words, there is an element of possibility. However, under the same principle of Luce and Raiffa the possibility of a choice is in direct ratio to its value. The above mentioned assumptions constitute the "strict utility choice mode". The exponential form of the value function: $V_{ij} = \exp[V(X_j, S_i)]$ is achieved by simple transformations of the "strict utility choice mode", where X and S have a linear correlation. The exponential functions of the total value have a sigmoid form relative to the linear function of the value of each possible choice. This means that the exponential function may have a sigmoid form relative to the X-axis or Y-axis, based on the defined axes and values.

The choice of any individual can be ascertained if there is a particular list of alternative transport means. The alternative situations should be independent to each other. The challenge exists to identify the relationships between the features of the individual and the features of the alternative situation, with which the value function V can be estimated. Accepting that the human behaviour defines the social value, then the social value is defined by the needs which each individual wants to satisfy. According to Maslow's Hierarchy of Needs[7], these needs belong to specific groups, which have the following hierarchy: [1] physiological needs, [2] safety needs, [3] love and belonging, [4] esteem and [5] self-actualization.

[5] Rodríguez-Pose, A. Government quality and the economic returns of transport infrastructure investment in European regions. Papers in Evolutionary Economic Geography (PEEG) 1535, (2015).

[6] Luce, R.D. & Raiffa, H. Games and Decisions. (New York: John Wiley and Sons, 1957).

[7] Maslow, A. Motivation and personality. (New York, NY: Harper, 1954).

The 'Physiological needs' category includes all the needs associated with the existence of humankind as a biological being, such as oxygen, water, food, clothing, health, etc. 'Safety needs' are after 'physiological needs' and include housing, permanent employment, pension, etc. The category 'love and belonging' includes the human need to belong to one or more social groups, to be accepted by them, to develop friendly relations, to gain and to offer love and affection. 'Esteem' includes prestige, fame, appreciation, respect of the environment, the need for success, competence, knowledge, independence, freedom, influence and power, but also self-respect and self-esteem. Finally, 'self-actualization' is the superior category of needs. It can never be fulfilled, since it includes the need of the individual to become what he/she wants, he/she dreams. Maslow developed value (utility) curves of each category of needs relative to the age of the individual.

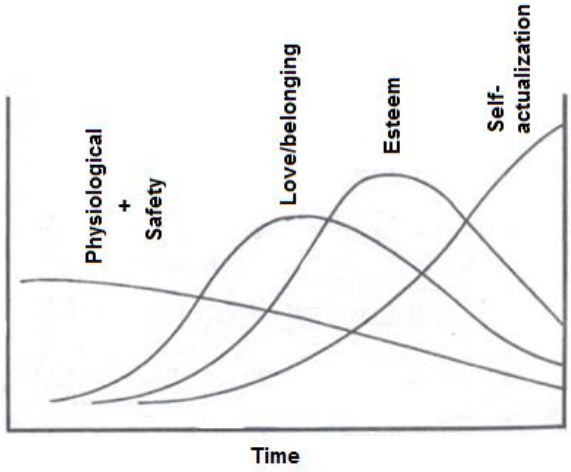

Figure 1: Value curves of Maslow's Hierarchy of Needs

Bourantas[8] used these curves to evaluate the investment behaviour of individuals relative to time in general. The sum of curves gives a sigmoid curve over time. Sustainability's approach of value critiques Maslow's value in terms of culture and society. Maslow claims that the individual, by trying reach 'self-actualization', benefits others or, "the greater good". This does not apply in individualistic societies, but only in collectivist societies[9]. The self-centred approach in the individualistic societies, sometimes, opposes "the greater good" in terms of environmental value. Therefore, within the social value the authors will not consider environmental value, but it will be studied separately.

Maslow's value resembles the value of business and economics' approach, as they are both linked with the satisfaction of the individual[10]. The main difference lies in economic constraints, as Maslow includes individual's wishes based on culture, environment and ethics, but without considering an individual's productivity or income. This research will consider an individual's income as a test factor and not as a

[8] Bourantas, D. Management. (Stamoulis Press, 2002)

[9] Cianci, R. & Gambrel, PA. Maslow's Hierarchy of Needs: Does It Apply In A Collectivist Culture. Journal of Applied Management and Entrepreneurship 8 (2), (2003).

[10] McKenzie, R.B. & Lee, D.R. Microeconomics for MBAs: The Economic Way of Thinking for Managers. (Cambridge University Press, 2006).

factor under investigation, meaning that it will not investigate how the income of an individual effects his/her choice, but it will be used for evaluating the transport behavior of the society.

So how can the social value of transport be expressed mathematically? Transport is a type of infrastructure. "Infrastructure generally conjures up the notion of a large-scale physical resource made by humans for public consumption" [11]. In traditional civil engineering, infrastructure is connected with major construction projects and more specifically in transport engineering it is connected with roads and highways, railroads, ports, airports, pipelines, canals, some owned by public entities and some owned by private corporations. The social value of an infrastructure will differ with a sigmoid form over time as Maslow's Hierarchy of Needs demands and over the value of each choice, as the strict utility choice mode demands.

Since the social value is so broad a Transportation Hierarchy of Needs is required aligning with Maslow's one. Winters et al.[12] did that and they found the following transport hierarchy of needs: [1] safety and security, [2] time, [3] societal acceptance, [4] cost and [5] comfort and convenience. Some researchers deviate from this ranking. Alfonzo[13] studied a specific transport mode, walking, and found that time is before safety. This may be explained from the fact that each transport mode may have a different ranking of needs. Winters et al. followed a wider approach by comparing different transport modes, so their approach is more proper for this research. This research will study value as something undivided effected from all the above factors and time, since the calculation of the value of each factor is unattainable in terms of dependency and each infrastructure expected to be in a different time of its lifecycle. This way the effect of the different rankings of needs will be reduced and time will be a part of the needs. So the total value of the individual, collectively, would have an almost sigmoid curve relative to the needs covered by transport, as a result of the sum of the value curves of Maslow's Hierarchy of Needs and of strict utility choice mode. In other words the hypothesis tested is: Social Value expected to have an almost sigmoid curve over the defined sub-values.

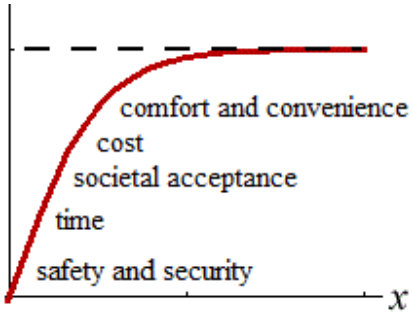

Figure 2: Expected Value curve of Transport

[11] Frischmann, B.M. Infrastructure: The Social Value of Shared Resources. (New York: Oxford University Press, 2012).

[12] Winters, P.L., Cleland, F., Mierzejewski, E. & Tucker, L. Assessing Level of Service Equally Across Modes. A report for the Florida Department of Transportation and NCTR: 1-53 (2001).

[13] Alfonzo, M. To Walk or Not to Walk?: The Hierarchy of Walking Needs. Environment and Behavior 37 (6), (2005).

Empirical Findings and Analysis

To define the total value and the sub-values, a structured interview process was held. The structured interviews aim to provide the required data to verify the sigmoid form of the social value. As previously elaborated, the metropolitan areas of United Kingdom, served by each type of transport mode, consist the targeted sample chosen to shed light on the tested hypothesis. The amount of citizens living in a metropolitan area served by each type of transport mode is 32,555,357, equating to 51.53 % of the total population of United Kingdom[14]. Purposive sampling was applied and the sample was chosen to ensure that the required factors are included[15] and the research gap will be filled[16]. Respondent criteria were established as it is required for targeted sample studies focusing on specific data[17]. The critical respondent criteria decided based on the age, gender, income, accessibility to each transport mode, number of cars and ethnic group. Additionally, the role and responsibilities of each individual should be identified as they are considered as key-stakeholders. This is not possible as the sample is big and it was decided to consider that all individuals have the same role and responsibilities during the stakeholder analysis. Based on the tested hypothesis, it is clear that there should be a specific amount of participants based on the critical respondent criteria.

Area	Population	Percentage	Expected
Belfast	585,996	1%	3
Birmingham	3,701,107	12%	36
Bristol	1,006,600	3%	9
Cardiff	1,097,000	3%	9
Edinburgh	1,339,380	4%	12
Glasgow	1,858,517	6%	18
Leeds	2,302,000	7%	21
Liverpool	2,241,000	7%	21
London	13,879,757	43%	129
Manchester	2,794,000	9%	27
Newcastle	1,650,000	5%	15
Total	32,455,357	100%	300

Table 1: Sample distribution per metropolitan area

Gender	Percentage	Expected
Male	49.11%	147
Female	50.89%	153
Total	100.00%	300

Table 2: Sample distribution per Gender

Ethnic group	Percentage	Expected
White	87.17%	262
Asian	6.92%	21
Black	3.01%	9
Other	2.90%	8
Total	100%	300

Table 3: Sample distribution per Ethnic group

[14] http://www.ons.gov.uk/. (2015).

[15] Silverman, D. Interpreting Qualitative Data (4th Edition). (London UK: SAGE Publications Ltd, 2011).

[16] Saunders, M., Lewis, P. & Thornhill, A. Research methods for business students (5th edition). (London: Pearson Education Limited, 2009).

[17] Mintzberg, H. An Emerging Strategy of "Direct" Research. Administrative Science Quarterly 24 (4), (1979).

Age	Total Percentage (%)	Survey (%)	Expected
0-15	17.6	0	0
15-19	6.3	7.65%	23
20-29	13.6	16.50%	50
30-39	13.1	15.90%	48
40-49	14.6	17.72%	53
50-59	12.2	14.81%	44
60-65	6	7.28%	22
65+	16.6	20.15%	60
Total	100	100.00%	300

Table 4: Sample distribution per Age

Considering the amount of individuals living in metropolitan areas, the authors believe that the samples, within the boundaries of the defined population and the delimitations of this study, will be diverse enough to contribute to different elements within the tested hypothesis. After setting the respondent criteria and getting the study ethically approved by the University of Birmingham, a pilot study was conducted in Birmingham, Leeds, Newcastle and London with 30 participants. The authors managed to test the questionnaire, to obtain basic insights on the expected outcomes. After the pilot study, the final version of the questionnaire was developed and the potential participants were contacted randomly in public areas in the aforementioned metropolitan areas which have all the possible transport modes as urban rail, light rail etc., so the individuals were able to compare the different transport modes. However, there was one exception. The age group of 65+ was approached at churches and/or social groups of elderly people (e.g. bingo hall), as they were difficult to find at random places outdoors. The study was conducted during rush hours 06:00-9:00, 11:00-14:00 and 16:00-19:00, when the individuals are often travelling for going to work, school or university. All interviews were conducted face-to-face to obtain immediate answers, expressions, gestures and to achieve a minimum common understanding of the questions by the individuals. In general, each interview lasted between 30 and 90 minutes (the most of them were around 45 minutes), excluding approaching time. The questionnaires used were only the completely filled for which the participants gave their consent to be used for this study. The participants asked questions in the questionnaire guidelines. This research studied value as something holistically affected by all the above factors (time, cost, comfort and convenience, safety and security) by asking individuals representative of the UK's demography to evaluate the social value of eight transport modes (walking, cycling, rail, bus, car, taxi, water and air) and each factor for each mode. "Societal and acceptance" need of Maslow's Hierarchy of Needs was removed from the questionnaire after the pilot study as the individuals were positively biased towards the transport mode they used the most without really considering the need itself. It was assumed that this need is included in the other factors. The accessibility of each individual to every transport mode was checked using the postcode. Finally, it was checked if the society is individualistic, to avoid sustainability's approach oppose by asking the individuals if they adjust their mode of transport to society by considering environment, other individuals etc. The 68.3% of the participants answered "No", which allow us to conclude that we have an individualistic society.

Transport mean	National	Expected		Percentage	Difference Distance
Walking	3%	3.09%	Walking	5.44%	2.35%
Cycling	1%	1.03%	Cycling	6.30%	5.27%
Rail	10%	10.31%	Rail	12.19%	1.88%
Bus	5%	5.15%	Bus	10.68%	5.53%
Car/Taxi	78%	80.41%	Car/Taxi	64.44%	-15.02%
Other	3%	-		0.94%	
Total	100%	100.0%	Total	100%	0.0%

Table 5: Usage of Transport Modes in the Metropolitan Areas

The usage of each transport mode in the metropolitan areas was compared with the national usage in the United Kingdom. As it was expected, Walking, Cycling, Rail and Bus usages in the Questionnaire Survey were found to be greater than the national usage by 2.4%, 5.3%, 1.9% & 5.5%, respectively. Car and Taxi usage in the Questionnaire Survey was found to be less than the national usage by 15.0%.

The holistic approach achieved by adding up each individual's evaluations of the factors for each transport mode and correspond this sum to the value estimated by the same individual for the transport mode. The next step was to try to fit a mathematical expression to social value. Additionally, the way the evaluation of the transport mode is defined ($-5 \le y \le 5$) creates a boundary value problem. When the raw data was drawn in a Cartesian coordinate system, the value to the individual, collectively, had an almost sigmoid curve. So we are looking for a sigmoid function which have as tangents $y = -5$ and $y = 5$. A wide variety of sigmoid function used. All functions were normalized in such a way that their slope at the origin is 1, as (0,0) is the origin for the Cartesian coordinate system and the maximum value of "5" corresponds to "1" of Y-axis. So some sigmoid functions compared based on the distribution of the individuals answers and on the convenience of designing them on the Cartesian coordinate system.

After plotting the raw data onto axes, curves were fitted to them as part of the analysis process. The fitting process was based on the common origin (0,0) and the maxima of Y-axis and X-axis. The maximum value "5" of the transport mode evaluation corresponds to 1 of Y-axis and the maximum 25 of the sum of the factors (time, cost, comfort and convenience, safety and security) for each mode corresponds to "2.45782" of X-axis (calculated by using the slope of our data and the distribution of the answers in the axis). For design and analysis convenience, it was assumed that the maximum sum of the factors "25" corresponds to the value "2.5" of X-axis, a safe assumption as the functions' results were rounded.

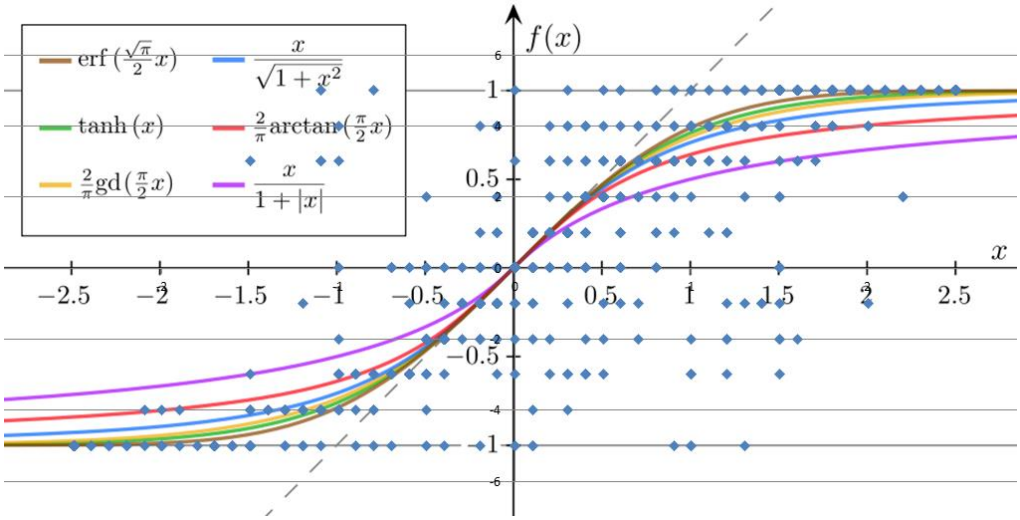

Figure 5: Fitting raw data onto sigmoid functions

After analysing and comparing previous sigmoid functions, by rounding the 2400 answers of the individuals and comparing them with the values given from the sigmoid functions , the two which mostly align with the curve are: $f(x)=\tanh(x)$ and $f(x)=\operatorname{erf}(\frac{\sqrt{\pi}}{2}x)$. The evaluation alignment without excluding the outliers showed the following results: 68.52% of evaluations explained with $f(x)=\operatorname{erf}(\frac{\sqrt{\pi}}{2}x)$, 68.41% of the evaluations explained with $f(x)=\tanh(x)$, 62.84% of the evaluations explained with $f(x)=\frac{2}{\pi}gd(\frac{\pi}{2}x)$, and 55.91% of the evaluations explained with $f(x)=\frac{x}{\sqrt{1+x^2}}$. Additionally, 3.18% of the evaluations explained only with $f(x)=\frac{2}{\pi}gd(\frac{\pi}{2}x)$ and/or $f(x)=\frac{x}{\sqrt{1+x^2}}$. In other words, $f(x)=\tanh(x)$ is closer to the 3.18% than $f(x)=\operatorname{erf}(\frac{\sqrt{\pi}}{2}x)$. The numerical expression that explains better our data is the hyperbolic tangent, as although an error function explains the most of our data, the hyperbolic tangent is closer to the data explained by the other two functions. Finally, the results of the second and the fourth quarters may be removed as outliers, since the total value had a different +/- sign from the sum of the sub-values, which means either they are a result of a subjective unpredicted factor or the evaluations were random or wrong. Then the percentage of data explained from the hyperbolic tangent is increased to 75%. The numerical expression of the hyperbolic tangent is a good fit to the data and the hypothesis was verified, as hyperbolic tangent is a solution to boundary value problems, as the one described in this study, and is a classic sigmoid function

Conclusions and Future Research Directions

The hypothesis was verified with some deviations, as the social value expected to have an almost sigmoid curve and the numerical expression of the hyperbolic tangent, which is a sigmoid function, is a good fit to the most of the data. The deviations were the result of the non-rational biased logic and misconception of the individuals. It was noticed that a lot of old individuals had negative and strong opinions about a transport mode, although their evaluations of the factors of each transport mode contrasted their initial evaluations. Additionally, other individuals evaluate in a mistakenly way the modes regarding time, cost and environmental impact, based on their misconception. To conclude the social value should get considered during the decision making process, but it is not a panacea as the misconception of the individuals does not allow us to consider them as a major rational "key-stakeholder".

Finally, considering the limited time and scope of this study, there are many things that can enrich it in the future. The extreme functions of several variables may give the best (maxima of the function) or the worst (minima of the function) combination of variables. Model optimization can be achieved by checking for possible extremes by finding when the gradient is equal to zero: $\nabla f = gradf = 0$. In this case, the social value function fits with the hyperbolic tangent function, which is defined for all real numbers and is strictly a monotonically increasing function. When this research started it was not expected to have a strictly monotonically increasing function, which is why it was originally thought to use the gradient. Now it is obvious that the maxima will be achieved at the infinity and of interest of this study is where the rate of change achieves the maxima ($f'' = 0$), as after that point the rate of the return of the value the individual gets starts to reduce.

Acknowledgements

The authors gratefully acknowledge the financial support of the UK Engineering and Physical Sciences Research Council (EPSRC) under grant numbers EP/K012398 (iBUILD: Infrastructure BUsiness models, valuation and Innovation for Local Delivery), EP/J017698 (Transforming the Engineering of Cities to Deliver Societal and Planetary Wellbeing, known as Liveable Cities) and UKCRIC (EP/P013635).